The astrophysics of extreme mass-ratio inspiral sources

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Overview

- Why EMRIs?
- Stellar dynamics and content near massive black holes
- Inspiral dynamics, loss-cone theory
- Dynamics within 0.01 pc: mass-segregation and resonant relaxation
- Alternative routes to EMRIs

Why are EMRIs important?

- Most detailed tests for general relativity
- Stellar content very close to massive black holes
- Stellar dynamics very near massive black holes
- Mass distribution of massive black hole
- Spin distribution of massive black holes; merger history
- Accretion disks
- Do intermediate mass black holes exit?
- Are massive black holes really black holes? (Or, let’s say, boson stars?)

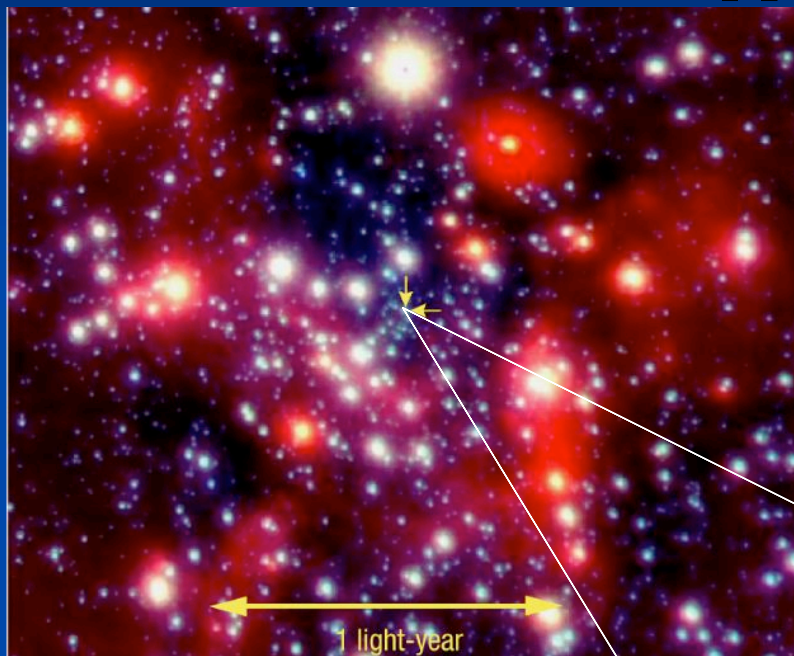
Stars near massive black holes

Infra-red observations of the Galactic center

- Very dense environment of stars
- Density diverges as a power-law: $n \sim r^{-(1.5-2)}$
- Short relaxation times (t_r<10 Gyr)
- Black hole dominates dynamics within ~1 pc.

Bahcall & Wolf 1976, 1977; Alexander 1999; Genzel et al. 2003

Stars near massive black holes



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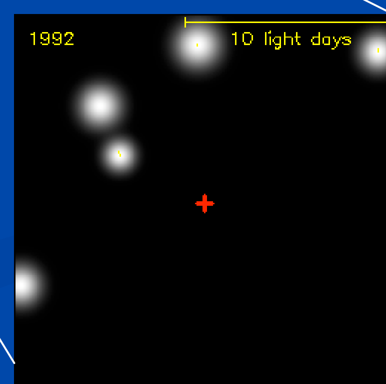

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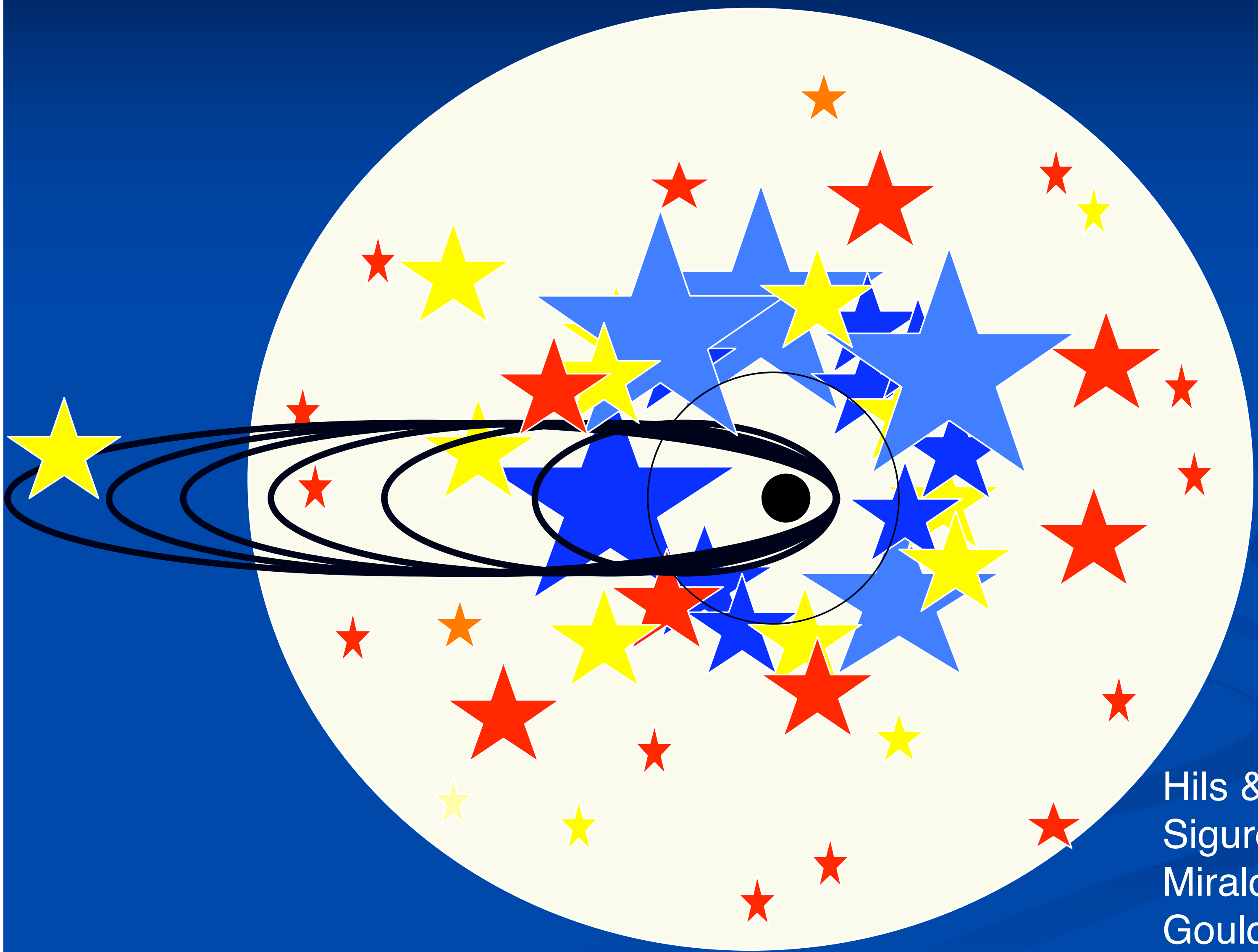
How to get near a massive BH



Hils & Bender;
Sigurdsson & Rees;
Miralda-Escude &
Gould; Gair; Freitag;
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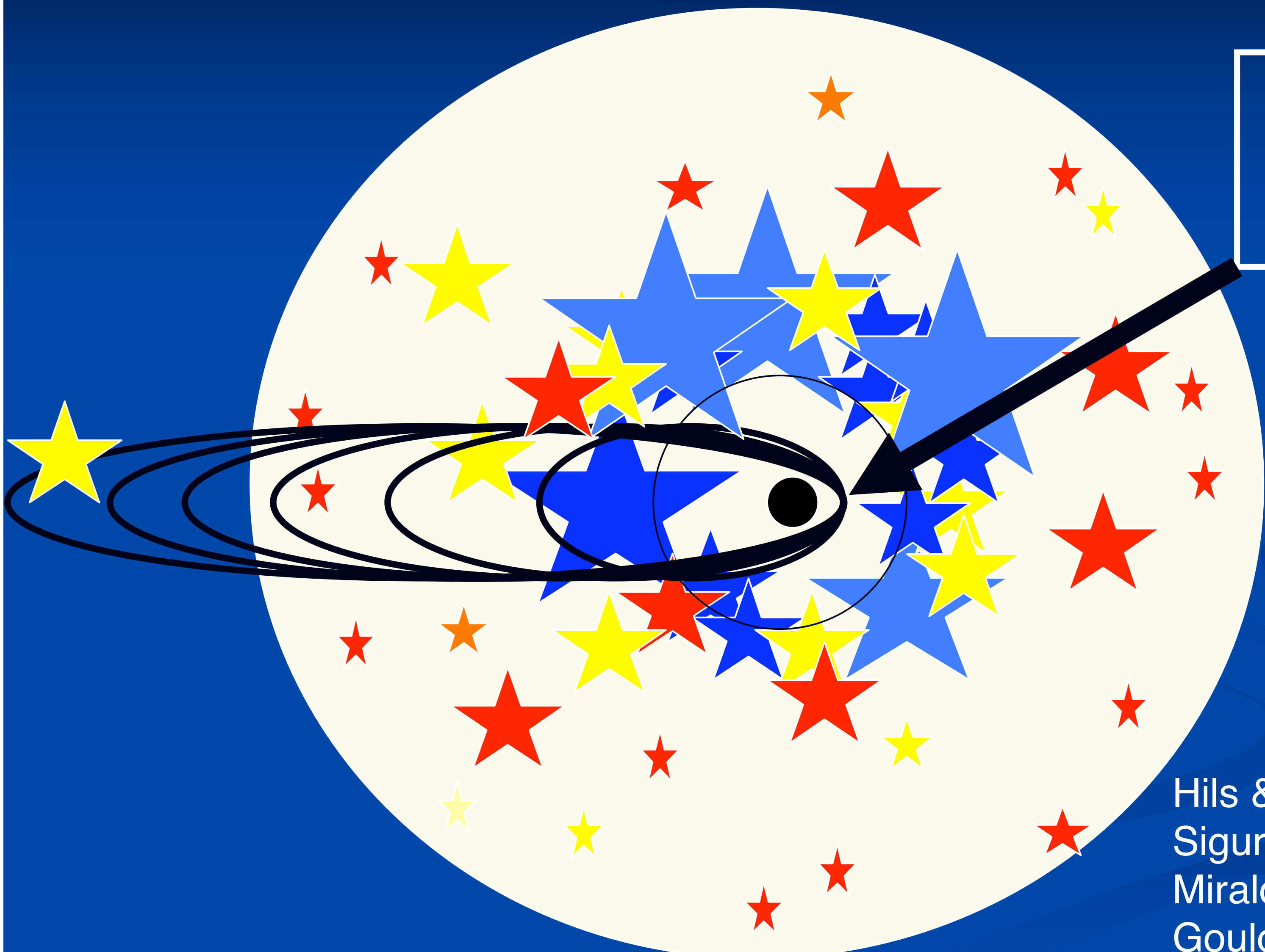
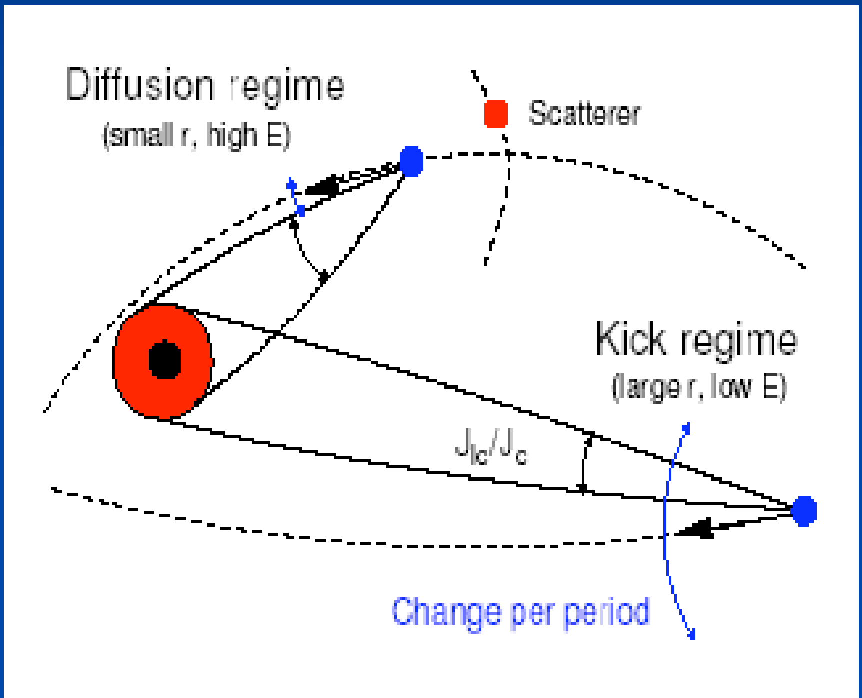


Bursts of GWs may be observable in our own Galactic center (Rubbo et al. 2006)

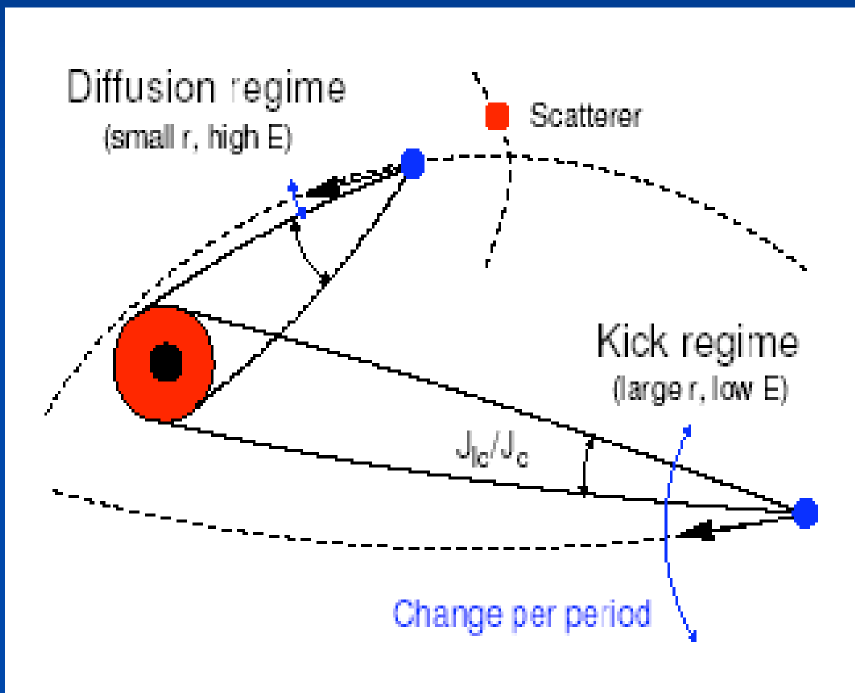
Hils & Bender; Sigurdsson & Rees; Miralda-Escude & Gould; Gair; Freitag; Ivanov; Hopman &

Loss-cone theory



Lightman & Shapiro (1977)

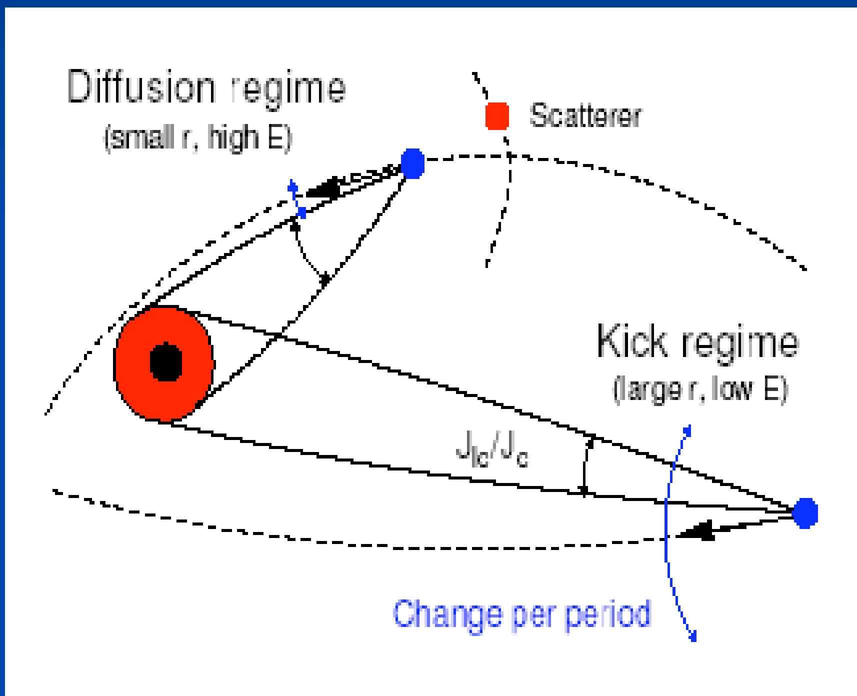
Loss-cone theory



$$\text{Kick regime:} \qquad \Gamma \sim \frac{N\vartheta^2}{P}$$

Lightman & Shapiro (1977)

Loss-cone theory

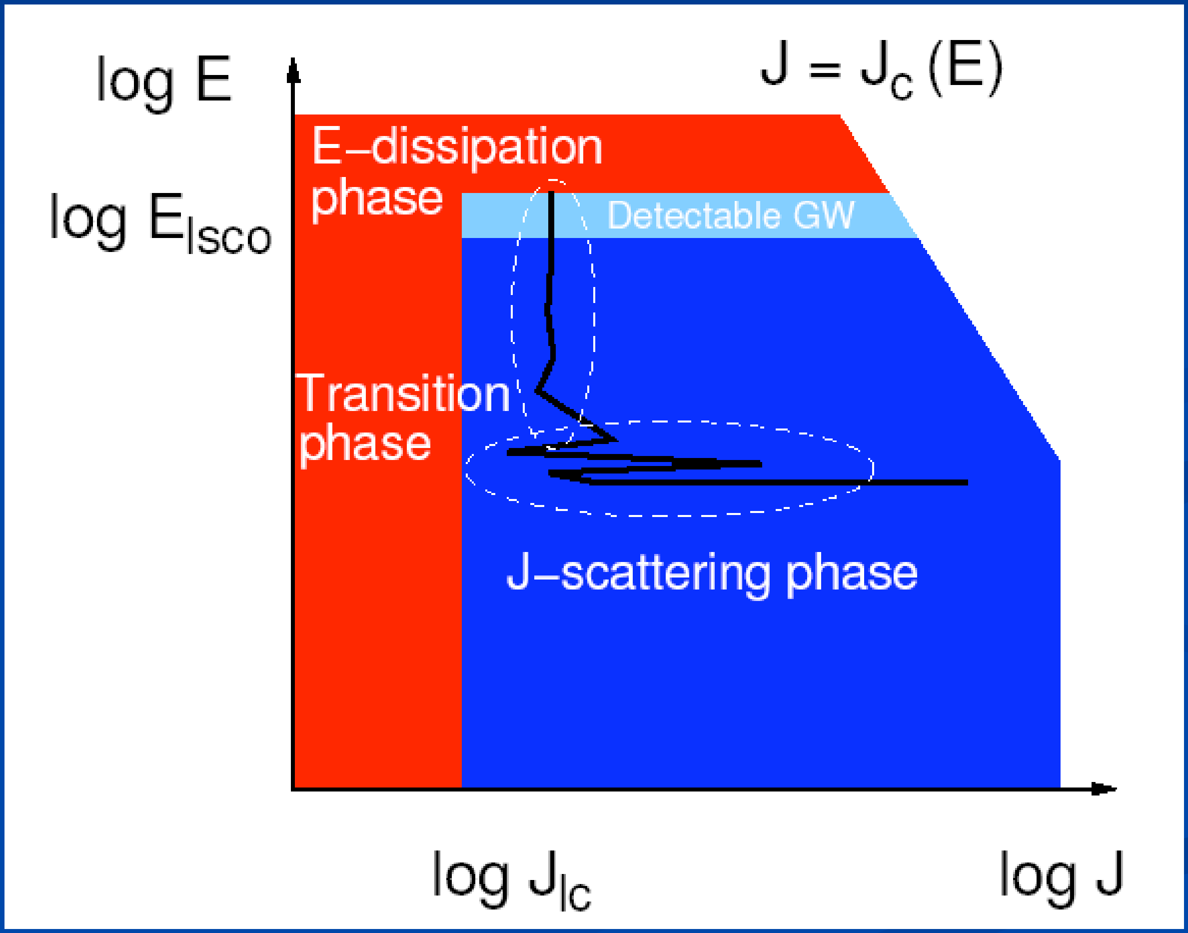


Kick regime: $\Gamma \sim \dfrac{N\vartheta^2}{P}$

Diffusion regime: $\Gamma \sim \dfrac{N}{t_r}$

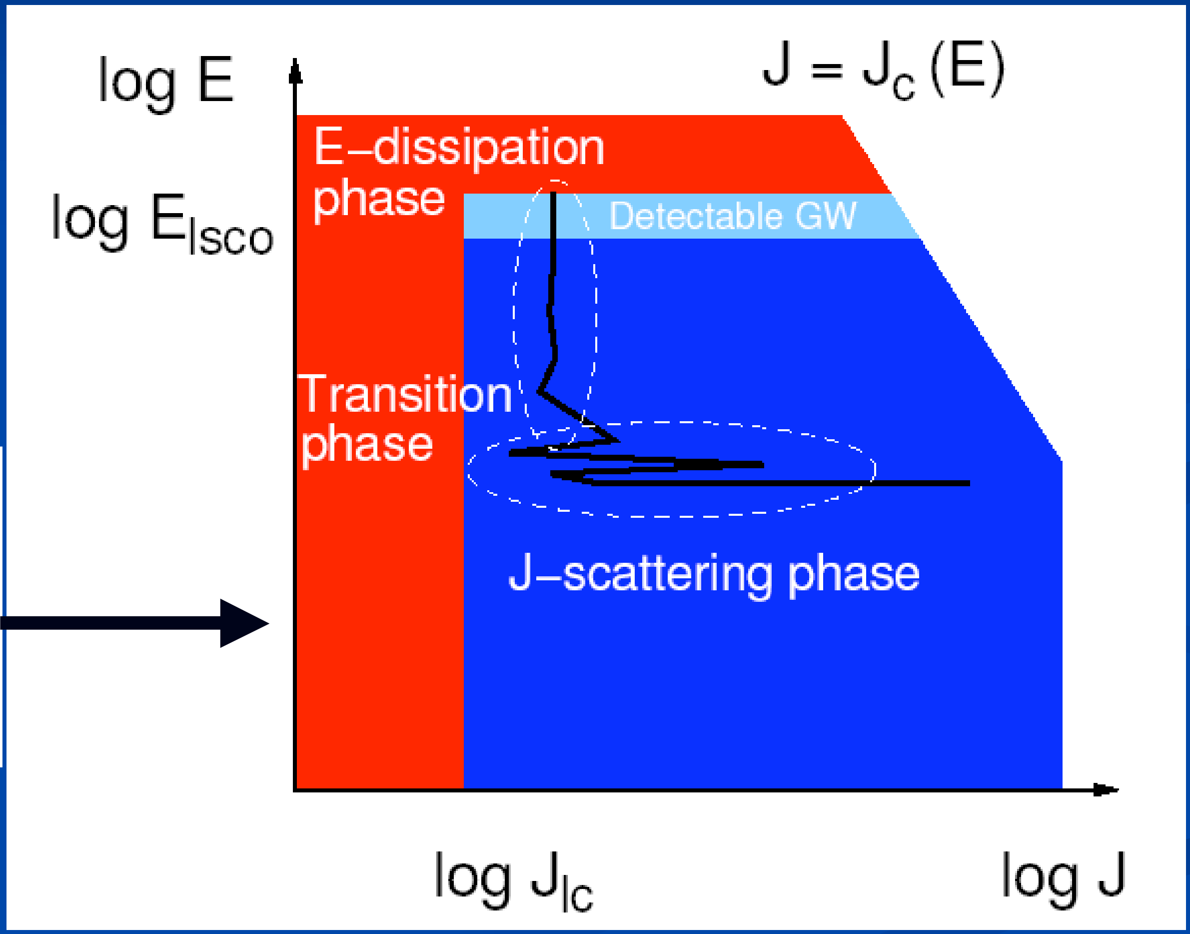
Lightman & Shapiro (1977)

Angular momentum scattering and energy dissipation



Hils & Bender (1995); Hopman & Alexander (2005)

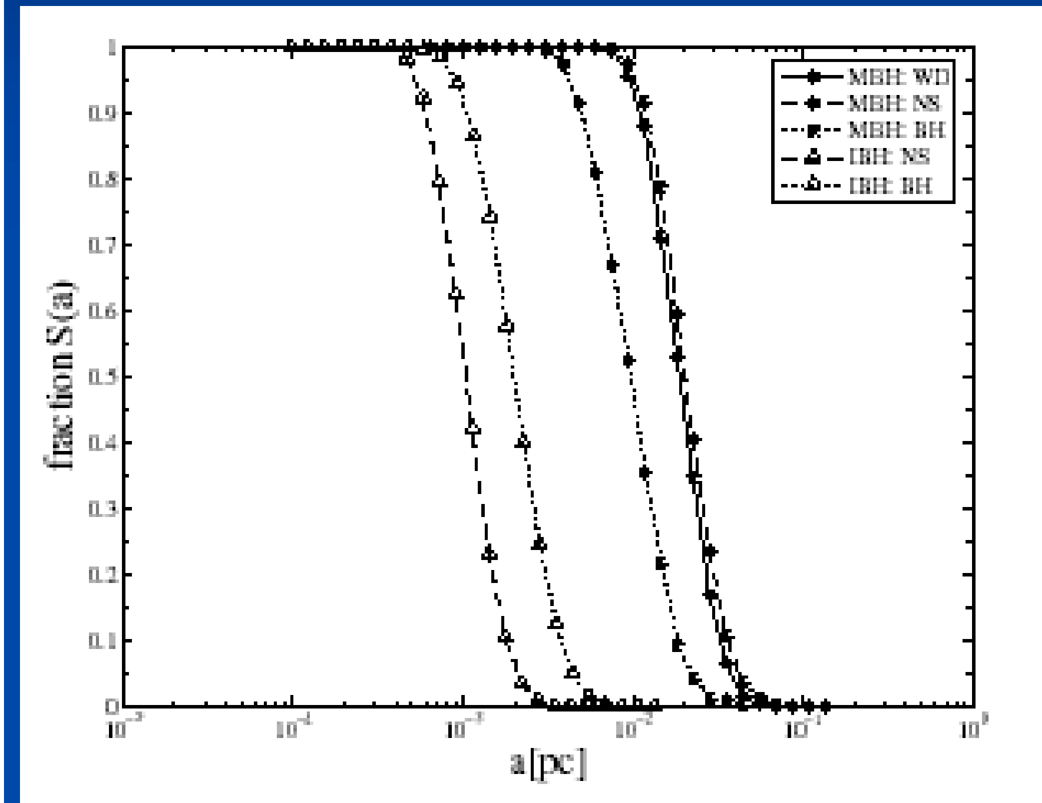
Angular momentum scattering and energy dissipation



Critical scale determined by equating inspiral time and scatter time near the LSO

Hils & Bender (1995); Hopman & Alexander (2005)

EMRI event rate

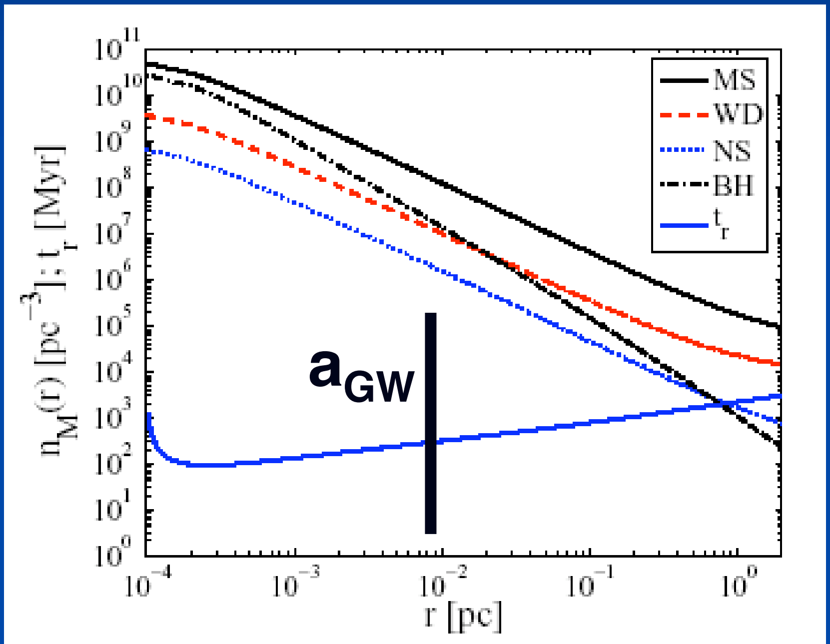


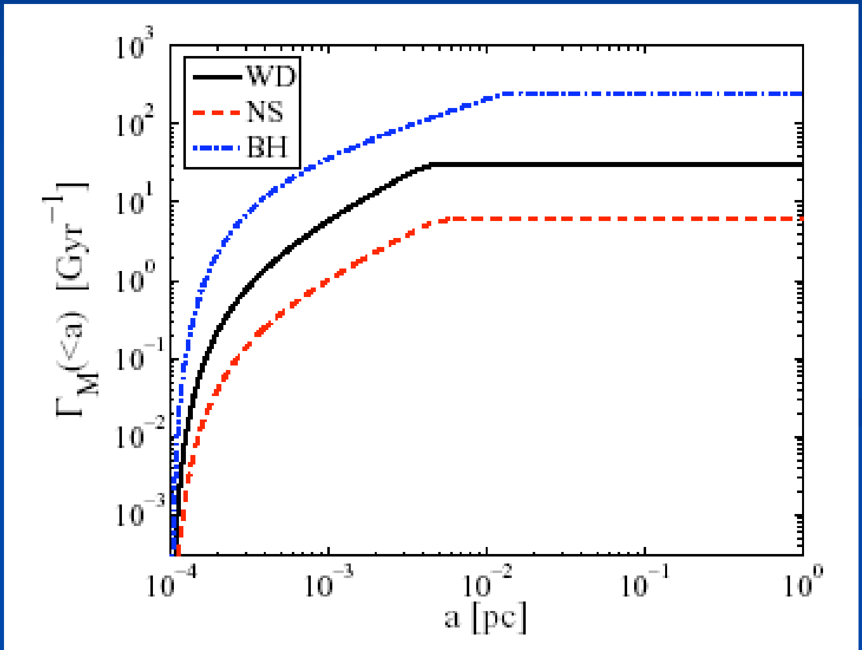
Hopman & Alexander (2005)

- Critical distance at a_{GW} =0.01 pc
- Nature of EMRIs determined by dynamics < a_{GW}
- Event rate: integrate diffusion expression over inspiral probability function:

$$\Gamma_i = f_s \int_0^\infty \frac{\mathrm{d}aN(a)S(a)}{\ln(J_m/J_{lc})t_r(a)}$$

Dynamics within a_{GW} : mass segregation

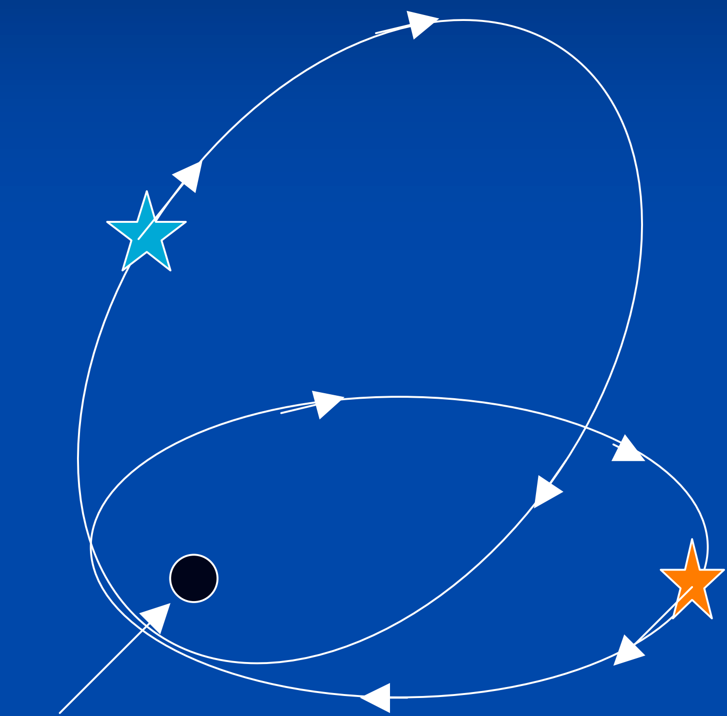


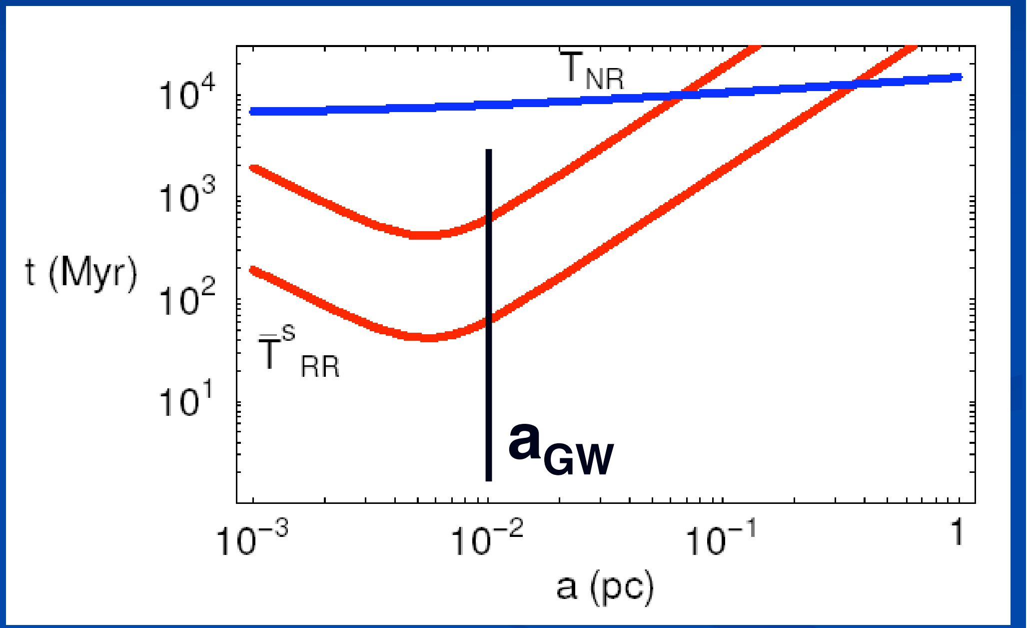


Stellar BHs sink to center and dominate dynamics within a_{GW}.
Relaxation time decreases due to presence of stellar BHs.

Hopman & Alexander (2006)
Freitag, Amaro-Seoane & Kalogera (2006)

Dynamics within a_{GW} : resonant relaxation





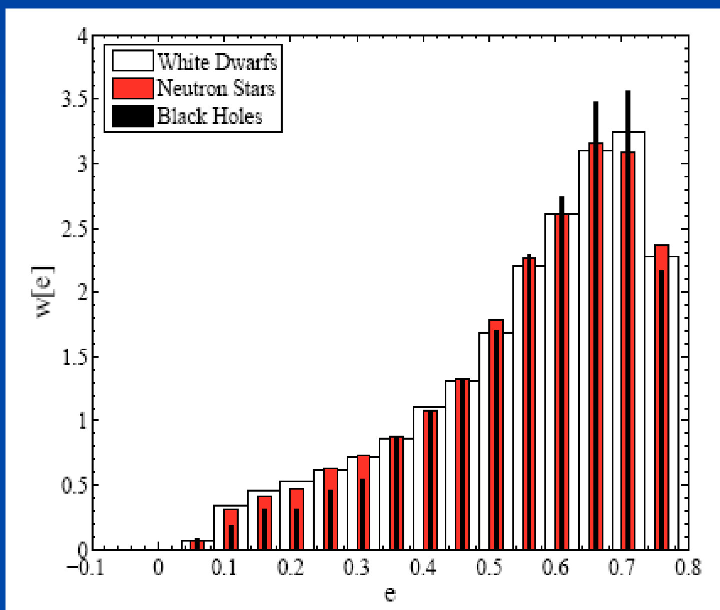
Resonant relaxation increases EMRI rate by factor
Crucial to include general relativity!

Rauch & Tremaine (1995)
Rauch & Ingalls (1998)

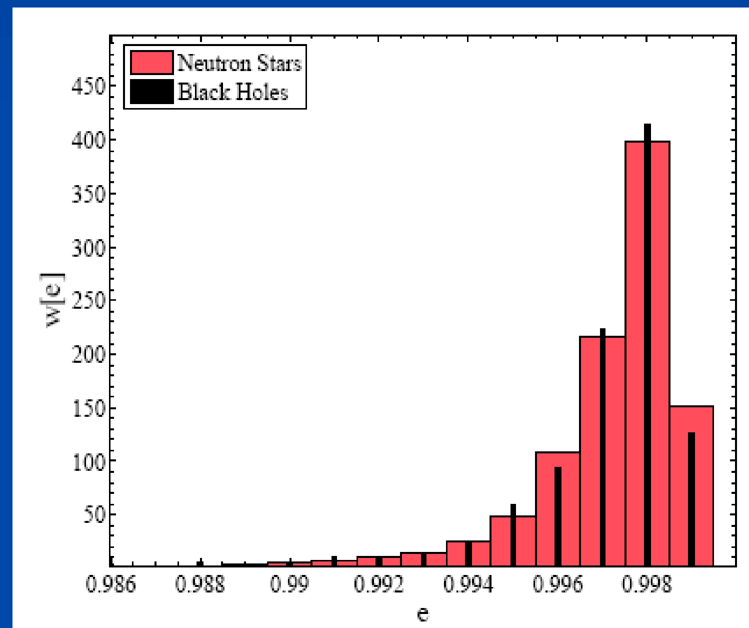
Hopman & Alexander (200

LISA EMRIs: high eccentricities at P=3 hrs

Massive Black Holes:



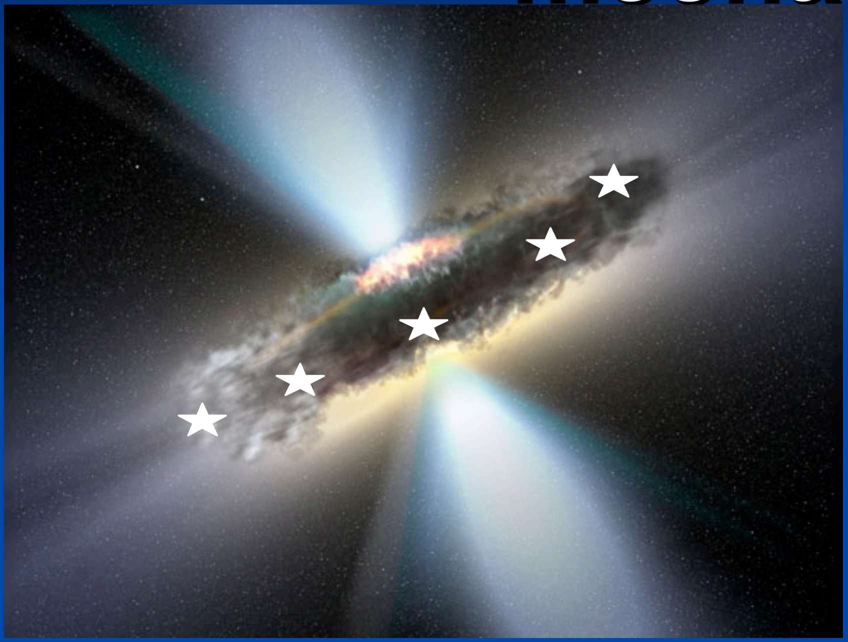
Intermediate Mass Black Holes:



Hopman & Alexander (2005)

Orbits must be modeled (pseudo-) relativist
Hopman & Alexander 2005; Gair et al. 200

Indirect EMRI capture mechanisms



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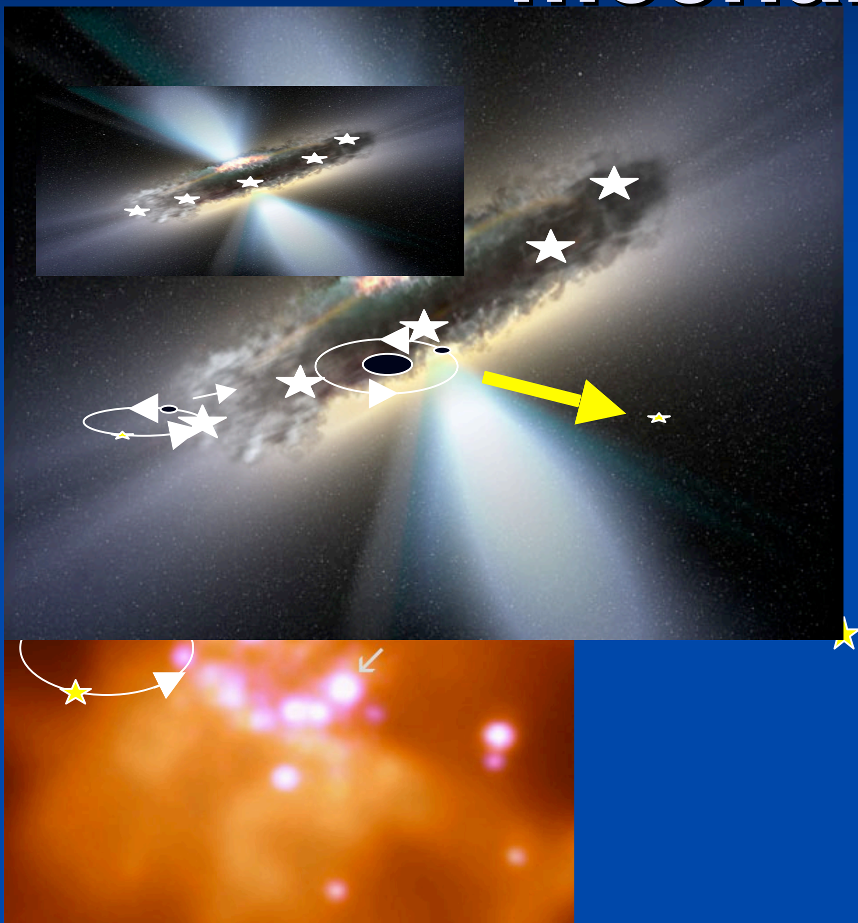

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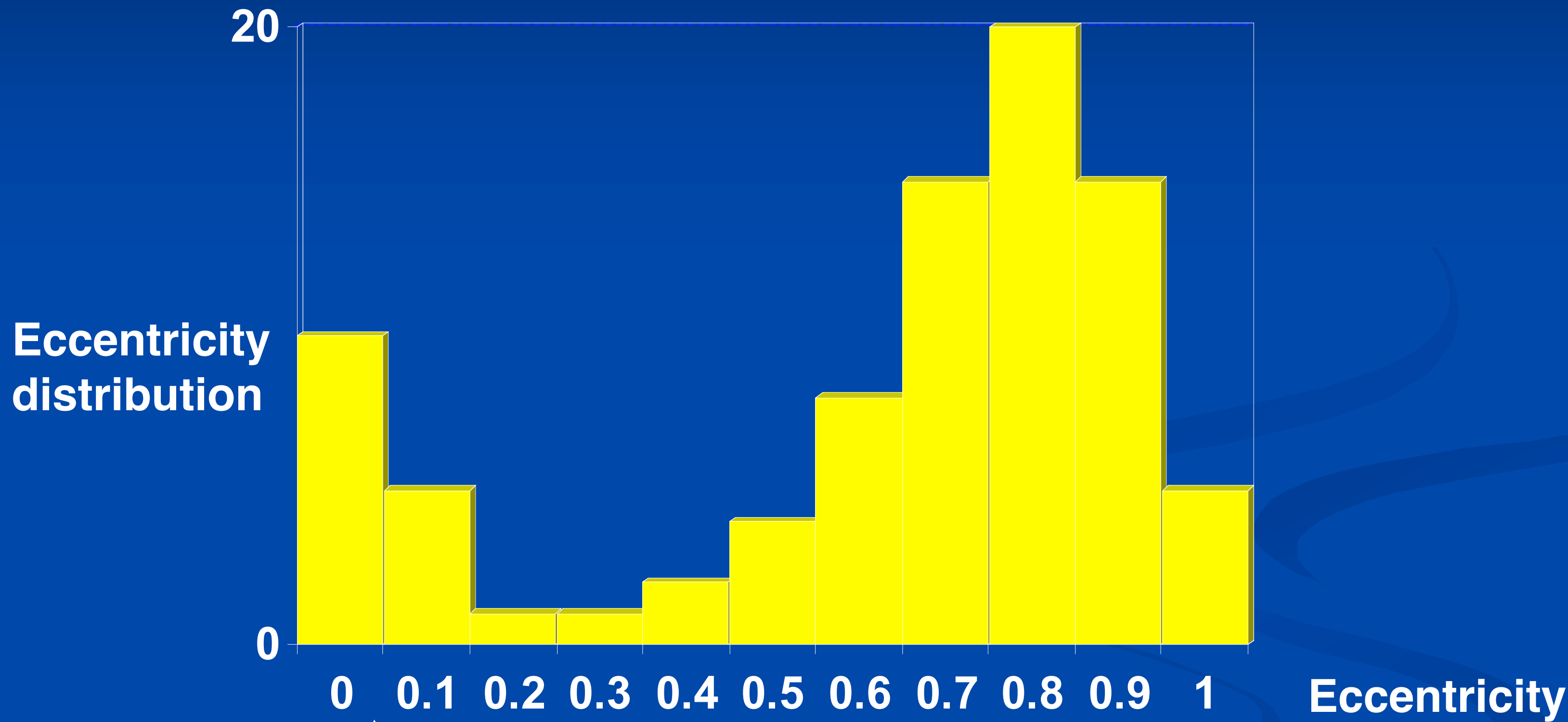
Binary stars are tidally disrupted, forming a hyper-velocity star and an EMRI (Miller, Freitag & Hamilton 2005)

Stars can be tidally captured by intermediate mass BHs. After an ultraluminous X-ray phase, they leave the main sequence and spiral in (Hopman et al 2004, Hopman & Portegies Zwart 2005)

Efficient loss-cone refilling by triaxiality (Holley-Bockelmann et al. 2006) and massive perturbers (Perets, Hopman & Alexander 2006)

A bimodal distribution of eccentricities?



Indirect EMRI formation (accretion disk, binary disruption, tidal caputre, ...)

Direct captures

Conclusions

- Direct captures: event rate of ~100/Gyr/MBH, but rather uncertain. Stellar BHs dominate rate
- Rates depend on dynamics within a_{GW}~0.01 pc: mass-segregation, resonant relaxation, …
- Direct capture sources are eccentric
- Indirect capture leads to low eccentricity EMRIs